REPORT NO. NADC 88109-60

THE EFFECTS OF PLASTIC MEDIA BLASTING PAINT REMOVAL ON THE MICROSTRUCTURE OF GRAPHITE/EPOXY COMPOSITE MATERIALS

Joseph Kozol, Steven Thoman and Kenneth Clark
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974

Final Report
October 7, 1988

Approved for Public Release
Distribution Unlimited

Prepared for
NAVAL AIR SYSTEM COMMAND
Department of the Navy
Washington, DC 20361

NOTICES

REPORT NUMBERING SYSTEM - The numbering of technical project reports issued by the Naval Air Development Center is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calandar year, and the official 2-digit correspondence code of the Command Officer or the Functional Department responsible for the report. For example: Report No. NADC 88020-60 indicates the twentieth Center report for the year 1988 and prepared by the Air Vehicle and Crew Systems Technology Department. The numerical codes are as follows:

CODE	OFFICE OR DEPARTMENT
00	Commander, Naval Air Development Center
01	Technical Director, Naval Air Development Center
05	Computer Department
10	AntiSubmarine Warfare Systems Department
20	Tactical Air Systems Department
30	Warfare Systems Analysis Department
40	Communication Navigation Technology Department
50	Mission Avionics Technology Department
60	Air Vehicle & Crew Systems Technology Department
70	Systems & Software Technology Department
80	Engineering Support Group
90	Test & Evaluation Group

PRODUCT ENDORSEMENT - The discussion or instructions concerning commercial products herein do not constitute an endorsement by the Government nor do they convey or imply the license or right to use such products.

APPROVED BY: W. F. Moroney DATE: 16 Dec 90

W. F. MORONEY
CAPT, MSC, U.S. NAVY

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NADC-88109-60	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Vehicle & Crew Systems Technology Dept. 6b. OFFICE SYMBOL (If applicable) Code 606	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Naval Air Development Center Warminster, PA 18974-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Air Systems Command 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Department of the Navy Washington, DC 20361	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
The Effects of Plastic Media Blasting paint Removal on the Microstructure of Graphite/Epoxy Composite Materials.

12. PERSONAL AUTHOR(S)
J. Kozol, S. Thoman, and K. Clark

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 10/86 TO 10/87	October 7, 1988	41

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Plastic Media Blasting (PMB), Graphite/Epoxy, (Gr/Ep) Composite Materials, Microstructure, Scanning Electron Microscopy (SEM), Optical Microscopy . (mjsu)
11	04		
11	03		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
Plastic Media Blasting (PMB) has been assessed as a paint removal method for AS4/3501-6 and IM6/3501-6 graphite/epoxy (Gr/Ep) composite materials. Microstructural effects on these composite materials were evaluated after repeated paint/blast cycles. Polyester (type I) and urea formaldehyde (type II) plastic media materials were used in a variety of blast conditions. Ultrasonic inspection, optical microscopy and scanning electron microscopy were used to assess the damage induced during paint removal. After one paint/blast cycle, most of the blast conditions caused little or no visual damage to the composite substrates. After four paint/blast cycles, several of the conditions caused minimal visual damage. Paint removal by sanding caused more visual damage after one paint removal cycle than any of the repeat blast conditions that were evaluated.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL J. Kozol, S. Thoman	22b. TELEPHONE (Include Area Code) (215) 441-7606/7273	22c. OFFICE SYMBOL Code 606

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

☆ U.S. Government Printing Office: 1986—607-044

UNCLASSIFIED

ACKNOWLEDGEMENT

The investigation of plastic media blasting (PMB) effects on graphite/epoxy microstructure was sponsored by V-22 and F/A-18 program offices at the Naval Air Systems Command. The authors wish to thank Mr. David Jamieson, the Naval Air Systems Command project focal point, for his coordination efforts with the program offices and his support. Mr. Bruce Thompson of the Boeing Helicopter Company conducted the blasting tests on composite panels. His cooperation during the testing and his informative discussions during the program are appreciated. The program was performed by the Aerospace Materials Division at the Naval Air Development Center. The following people are acknowledged for their contribution to this program:

Mr. Dickson Alley & Mr. Bernard J. Duffy	Gr/Ep Specimen Fabrication
Mr. William Weist	SEM Sample Preparation
Mr. Donald Hirst	Coating Application
Mr. Sydney Oliver	Ultrasonic Inspection

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 ABSTRACT

Plastic media blasting (PMB) has been assessed as a paint removal method for AS4/3501-6 and IM6/3501-6 graphite/epoxy (Gr/Ep) composite materials. Microstructural effects on these composite materials were evaluated after repeated paint/blast cycles. Polyester (type I) and urea formaldehyde (type II) plastic media materials were used in a variety of blast conditions. Ultrasonic inspection, optical microscopy and scanning electron microscopy were used to assess the damage induced during paint removal. After one paint/blast cycle, most of the blast conditions caused little or no visual damage to the composite substrates. After four paint/blast cycles, several of the conditions caused minimal visual damage. Paint removal by sanding caused more visual damage after one paint removal cycle than any of the repeat blast conditions that were evaluated.

2.0 INTRODUCTION

Fiber reinforced composite materials are currently being used on Navy aircraft as flight critical and secondary structure. During the operating lifetime of an aircraft, paint stripping and recoating of its exterior surfaces are periodically required. Typical paint systems include coatings for corrosion protection, visual camouflage, walkway surfaces, and rain erosion protection. Historically, paint removal has been achieved with the use of chemical strippers which contain toxic components such as methylene chloride and phenol [1,5]. This process generates hazardous waste which requires expensive disposal procedures [2,3]. The chemicals used are health hazards because they add to the total toxic organic waste water load and produce volatile organic compound pollutants. Recent legislation has made disposal restrictions on these wastes more stringent. In addition, the use of chemical solvents can cause resin plasticization and result in strength losses in organic matrix composite materials [4]. Alternatives to chemical paint removal from composite surfaces of aircraft include scuff sanding, laser paint stripping and plastic media blasting (PMB). Sanding with abrasive paper or cloth is laborious, time consuming and impractical for complete paint removal of large areas; however, scuff sanding the topcoat on naval aircraft is an accepted interim procedure during the preparation of composite structure for repainting. Laser removal methods offer the potential for rapid, automated coating removal from aircraft surfaces; however, this process has not yet been developed sufficiently for large scale stripping nor has its effects on materials been determined. PMB has the potential for efficient removal of coatings from a variety of substrates without hazardous waste disposal problems or loss of strength to the structure. PMB equipment is currently available for large scale paint stripping. However, the conditions for blasting Gr/Ep components have not been optimized. Specifically, it has not been shown that Gr/Ep composites can be blasted repeatedly without deleterious effects to the microstructure or mechanical properties.

The objective of this study was to identify the parameters that can be used to remove paint repeatedly from Gr/Ep substrates by direct pressure blasting while inducing little or no damage to the material's microstructure. In phase I of this study, the effects of nozzle pressure, angle of attack, stand-off distance, media material and particle size distribution were investigated. During phase II, six of the phase I conditions were selected to assess the effects of four paint/blast cycles on the microstructure of Gr/Ep.

3.0 EXPERIMENTAL APPROACH

3.1 PHASE I - PROCESS PARAMETER SCREENING: ONE BLAST CYCLE

The effects of blast parameters on the microstructure of AS4/3501-6 Gr/Ep composites were investigated during the first phase of this study and compared with sanding to the substrate. Two media materials were evaluated: polyester (type I) and urea formaldehyde (type II). Previous studies have shown that for a given media flow rate, the coating removal rate depends on the blast media material, media size, nozzle pressure, angle of attack and distance of the nozzle from the substrate [5-16]. Although some of these studies included work with Gr/Ep composites, they did not provide an adequate evaluation of the microstructural effects caused by PMB. For this study, a test matrix was developed for an unrecycled 30-40 U.S. sieve size blast media (.015-.023 in.). The test matrix represents a two-level full factorial experimental design without replication and is shown in Table 1. Another test matrix was used to assess the effects of an unrecycled 20-30 U.S. sieve size (.021-.038 inch) particle size and is shown in Table 2. Additional tests were run to evaluate the effects of extended dwell time. The increased dwell time was achieved by increasing the PMB exposure by a factor of five for selected conditions. These conditions are shown in Table 3.

The effects on the composite surfaces were assessed using both optical and scanning electron microscopy (SEM). Optical microscopy was also used to examine the material cross-section for evidence of subsurface damage.

3.2 PHASE II - EFFECTS OF REPEAT BLASTING: FOUR BLAST CYCLES

Six blast conditions from phase I were used for the repeat blast evaluation in phase II. These conditions, shown in Table 4, were selected based on the extent of damage and the time to remove the paint.

After each blast cycle, the panel surfaces were examined by optical microscopy and then repainted. Upon completion of all four blast cycles, panel damage was assessed using ultrasonic C-scan inspection, SEM, and optical microscopy of specimen cross-sections.

4.0 EXPERIMENTAL PROCEDURE

4.1 SPECIMEN PREPARATION

Two Gr/Ep materials were selected as substrates for paint removal testing. AS4/3501-6 unidirectional tape was chosen for evaluation in phase I and phase II because of its structural applications on AV-8B and F/A-18 aircraft. IM6/3501-6 unidirectional tape was evaluated in the second phase of this study due to its proposed use on the tilt rotor V-22 aircraft and the A-6 rewing. Eight ply [0/90]2s laminates were fabricated for phases I and II using hand layup techniques. The AS4/3501-6 material was bagged and cured according to the McDonnell Douglas Process Specification 14240 [17] which governs the cure of AV-8B parts and is shown in figure 1. The IM6/3501-6 material was cured according to the Bell Process Specification No. 299-947-330 [18] used to process V-22 composite parts and is shown in figure 2. The quality of the laminates was assessed after cure by pulse echo ultrasonic C-scan inspection using a 25 MHz transducer at a 0.015 inch increment. The composite laminates were then cut into 6 inch by 6 inch test panels on a band saw with a diamond grit blade. Test panels were painted with solvent-borne epoxy/polyamide primer (MIL-P-23377) to a dry film thickness of approximately one mil and topcoated with aliphatic urethane (MIL-C-83286, Color No. 36440) to a total paint system film thickness of approximately three mils. Painted panels were dried at ambient laboratory conditions for seven days and then baked for seven days at $150^{\circ}F$ to eliminate solvent plasticization of the paint film.

4.2 PMB EQUIPMENT AND PAINT REMOVAL PROCESS

Plastic media blasting was performed by the Manufacturing Technology Department at Boeing Helicopter Company using a Caber, Inc. "Becuna" plastic media blasting machine as shown in figure 3. New media was processed through the machine to eliminate contaminants before it was used in the paint removal process. Dust and light particles were removed in an air wash and cyclone swirl chamber. The material was then passed through a vibrating screen separator, which removed oversize particles on a 16 mesh screen. A 60 mesh screen was also used to remove undersized particles. The media was then passed over a magnetic trap with deflectors, which forced all particles to pass within 0.5 inches of powerful magnets for removal of ferromagnetic contaminants. A sifting type of distribution onto the magnets precluded abrasion and pull-off of trapped particles. An additional air wash and heavy particle separation was then performed by metering the media in the moving air stream. This process lifted the media 10 feet, passed it through another cyclone swirl baffle chamber and into a reservoir. The media fell from the reservoir into a pressure vessel through a mushroom valve. The vessel was pressurized by closing the mushroom valve and filling the vessel with air. Two separate regulators, one controlling vessel pressure and the other air line pressure, maintained the proper overbalance to assist media flow through an adjustable restriction and into the moving air stream when blasting commenced. The combined air-media mixture was transported through 50 feet of 1.25 inch diameter hose to a 0.5 inch diameter Venturi nozzle.

All air was delivered through a water/oil trap and through a regenerative dryer/filter. Pressure settings were measured by means of a needle pressure gage which was inserted in the line just before the nozzle. Media flow rates were determined by blasting for a measured period of time into a baffled collector, weighing the collected media and calculating the flow rate. Fine tuning of the flow rate was accomplished by means of an adjustable restriction at the bottom of the pressure vessel. Flow rates were kept between 600 and 800 lb./hr. for phase I and maintained at 700 lb./hr. +/- 5% for phase II. In order to control the duration of blasting, a "dead-man" switch at the nozzle was used to control a pneumatic pinch valve located in the air-media flow stream. Operation of the equipment for the plastic media blasting tests was intended to simulate the conditions which would exist in blasting an aircraft surface. A cabinet configuration was not used in this study so that flow disruption caused by media rebound from the walls of the box could be eliminated.

The test panels were held in an aluminum frame which was designed to minimize specimen flexure during blasting and to eliminate edge effects. The angle of attack was estimated and the nozzle distance from the specimen was measured. The time to remove the topcoat and primer was recorded.

For purposes of comparison, panels were sanded by Manufacturing Technology personnel at Boeing Helicopter Company with a 180 grit "jitterbug" sander normally used for aircraft paint removal. The instructions given to the operator were to remove all topcoat and primer from the laminate.

4.3 MICROSTRUCTURAL EVALUATION

Nondestructive inspection, optical microscopy and scanning electron microscopy were used to evaluate the effects of PMB on the composite materials. Pulse echo ultrasonics were used to scan the composite specimens after PMB paint removal and compared to the results obtained before painting. A Nikon Optiphot-M optical microscope was used to examine both the surfaces and the cross-sections of the specimens before and after PMB paint removal. Samples used for cross-sectional examination were cut on a milling machine with a diamond grit blade before being mounted and polished to insure that no damage was induced during cutting. The surface samples were also evaluated with a scanning electron microscope (SEM). These samples were cleaned with an ultrasonic vibration technique and sputter coated with gold before examination from 20x to 1000x on an AMRAY model 1000A SEM.

5.0 RESULTS AND DISCUSSION

Many of the PMB process conditions studied in phase I and phase II caused minor damage to the Gr/Ep substrates after primer/topcoat removal. Surface and subsurface damage was evaluated with optical microscopy, scanning electron microscopy, and NDI. The surface damage was qualitatively assessed and the results have been categorized as follows: 0 - control material, no visible signs of damage; 1 - minor surface abrasion, release ply pattern clearly visible, no fiber damage; 2 - extensive resin abrasion, release ply pattern visible, minor fiber damage; 3 - release ply pattern no longer visible, extensive fiber damage; 4 - damage extends into the second ply.

An example of a control panel is shown in figure 4; no painting and blasting was performed on the control specimens. The resin "cross-hatch" pattern from the release ply is clearly visible in figure 4(a).

A composite surface that is typical of category 1, the category of least damage, is shown in figure 5. Minor surface abrasion can be seen when figure 5(a) is compared to figure 4(a). Note that the release ply pattern is clearly visible in figure 5(a) and no damage to the graphite fibers can be seen.

Under more severe PMB conditions, increased resin abrasion and a small amount of localized fiber damage occurs. This type of damage is typical of category 2 and is shown in figure 6. The release ply pattern is still visible in figure 6(a) and some scattered areas of fiber fracture can also be seen. A higher magnification photomicrograph of one of these fiber fracture areas is shown in figure 6(b); however, most of the surface does not contain fiber damage.

The type of damage grouped into category 3 is shown in figure 7. Increased abrasion of the surface has occurred and the release ply pattern can not be recognized in figure 7(a). Unlike category 2, the damage to the graphite fibers in category 3 is much more extensive and occurs over most or all of the surface of the laminate. A typical fiber fracture area is shown in figure 7(b).

Under extreme PMB process conditions, damage can extend through the first ply and into the second ply in some localized areas of the laminate. If the second ply was visible anywhere on the surface of the specimen, the PMB condition was grouped into the fourth category. An example of this category is shown in figure 8. Note that the fibers in the second ply are visible and can be distinguished from the fibers in the first ply because they have an orientation perpendicular to the surface ply fibers.

5.1 PHASE I - PROCESS PARAMETER SCREENING: ONE BLAST CYCLE

The phase I PMB test results are presented in Table 1 and Table 2. Most of the conditions caused only minor surface abrasion without fiber damage after one PMB cycle and were grouped into category 1. This type of damage is shown in figure 5. Some of the laminates exhibited category 1 damage in some areas while showing more severe category 2 damage in other areas. These processes were rated 1-2 to reflect the variation in damage on the surface of the 6 inch by 6 inch composite panel. The resin abrasion and minor fiber fracture typical of category 2 are shown in figure 6. The effect of changing the blast angle from 90 degrees to 45 degrees had a more significant effect on the surface damage than did varying the stand-off distance from 24 inches to 12 inches or than varying the nozzle pressure from 25 psi to 35 psi Although it took less time to remove the primer/topcoat with the type II media, the type II media was found to be more aggressive to the composite surface than was the type I media. Most of the damage induced during 45 degree angle testing with type II media was typical of category 2.

The results of the extended dwell testing are presented in Table 3. When specimens were blasted with the type II media, the surface resin was completely removed and extensive fiber damage occurred. In some cases, the damage extended through the first ply into the second ply. This type of damage is shown in the SEM photomicrograph of figure 8. Extended blasting with the type I media did not result in such extensive deterioration. The composite surface became warm from blasting, but the surface damage did not extend beyond the stage of mild abrasion.

No subsurface damage was evident in any of the laminates tested under phase I blast conditions. Ultrasonic C-Scan showed no evidence of damage when compared to the results obtained before blasting. Cross-sectional optical microscopy of blasted specimens up to 400x magnification showed that none of the process parameters evaluated in this study caused any subsurface delaminations or microcracking. A cross-section of a control sample is shown in figure 9 and a cross-section that was blasted under the worst set of PMB parameters is shown in figure 10. Note that this is the same sample as that shown in figure 8 where damage extended into the second ply. The blasted surface is shown at the top of the photograph and it can be seen that the damage did not occur beneath the surface. All of the PMB process conditions that were investigated result in a surface erosion effect on Gr/Ep materials without causing subsurface damage.

Examination of the panels after sanding revealed that paint removal was non-uniform. The samples had areas of complete coating removal and other areas with the primer remaining. SEM photomicrographs of the surface are shown in figure 11. The lower photomicrograph, taken at 500x, shows that considerable fiber damage has occurred. The surface damage rating for this paint removal method falls into category 3 since the release ply pattern is no longer visible and extensive fiber damage is evident.

5.2 PHASE II - EFFECTS OF REPEAT BLASTING: FOUR BLAST CYCLES

The average paint removal rates from the four blast cycles and the phase II results obtained from optical and scanning electron microscopy are shown in Table 4. The phase II blast conditions caused little damage to the Gr/Ep composite materials after four paint/blast cycles; in fact, they caused less damage than sanding to the substrate a single time (figure 11). Photomicrographs of Gr/Ep materials blasted with the type II media are shown in figures 12 and 13. Most of these conditions caused extensive resin abrasion from the surface and some fiber fracture. The type I media caused less damage to the composite substrates than the type II media did. Specimens blasted with the type I media are shown in figures 14 and 15. The damage consisted mainly of abrasion to the surface resin with only minor fiber fracture. One of the conditions blasted with type I showed no evidence of fiber fracture at all. Some small cracks were apparent at 500x in the surface of the composites which did not exist after one cycle (figure 14b). These small cracks were further assessed in the subsurface damage investigation.

The composite subsurface damage was investigated with NDI and optical microscopy of the laminate cross-sections. The pulse echo ultrasonic C-scan inspection performed at the completion of the fourth blast cycle revealed no subsurface defects. Examination of composite cross sections up to 1000x revealed no subsurface delaminations or cracking. An example of a repeat blasted cross-section is shown in figure 16. Note that this is the same sample whose surface is shown in figure 14. The small resin cracks that were evident in the SEM surface assessment did not extend past the resin rich area at the surface.

6.0 CONCLUSIONS

The microstructure of unidirectional graphite/epoxy laminates was assessed after paint removal with plastic media blasting (PMB). Five independent process variables were investigated: media material, media size, nozzle pressure, angle of attack, and stand-off distance. The damage to the microstructure was evaluated using ultrasonics, optical microscopy, and scanning electron microscopy. From this study, the following conclusions were made:

1. One cycle of PMB paint removal can be performed on Gr/Ep with only minor surface abrasion to the resin. This was demonstrated with a variety of process conditions using both polyester (type I) and urea formaldehyde (type II) media materials.

2. Type I media caused less damage to Gr/Ep microstructure than the type II media. Increasing the dwell time to five times the coating removal duration caused severe damage with the type II media. Little change in the microstructure was seen after extended dwell exposure with the type I media. This indicates that the type I media is less sensitive to operator error than the type II media.

3. Minor surface damage was observed in the composite materials after four paint/blast cycles. One condition was found to cause only resin abrasion and no fiber damage after four paint/blast cycles. However, the use of both type I and type II media caused small surface cracks in the resin after four paint/blast cycles. These cracks did not extend past the resin rich surface of the composite.

4. Very little difference in damage was seen between AS4/3501-6 and IM6/3501-6 Gr/Ep composite materials.

7.0 RECOMMENDATIONS

The use of PMB as a cost effective method to remove coatings from composite aircraft structure appears to be promising; however, several issues require further investigation. The long term effects of repeat blasting on the mechanical performance of composites must be thoroughly assessed. The strength and stiffness properties should be measured under static loading. An investigation into other types of composite material configurations is also required to fully assess the applicability of PMB. Honeycomb construction and lightning strike protection schemes are some examples of composite structure that require evaluation. Although little difference was seen between AS4/3501-6 and IM6/3501-6, other matrices may be more susceptible to damage from PMB. For instance, bismaleimide resins used for higher temperature applications have lower fracture toughness properties than epoxies and may require less aggressive blast conditions or media materials. Furthermore, all of the PMB coating removal conditions evaluated in this study were performed with media that was not recycled. An evaluation of the effects of media contaminants on structural materials is required to implement PMB into the Naval aircraft rework process.

8.0 REFERENCES

1. "Threshold Limit Values for Substances in the Workroom Environment", American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1987-88.

2. T. Byers, "PRAM Project Paint Stripping of F-4 Aircraft and Component Parts Using Mechanical Methods", Final Report, Project No. 00-143, Ogden Air Logistics Center, Hill Air Force Base, Utah, 11 August 1986.

3. "Economic Analysis for Recycling Plastic Media", Report No. CR87.001, Naval Civil Engineering Laboratory, Feb 1987.

4. S. Spadafora, "The Effects of MIL-R-81294 Paint Stripper On AS/3501-6 Graphite/Epoxy Composite Systems", Report No. NADC-85003-60, Naval Air Development Center, 22 May 1984.

5. C. McDonald and C. Walbach, "Plastic Media Blasting: Summary of Current Activities", Acurex Corporation, EPA Contract No. 68-02-3993, vol. I, Jan 1986.

6. T. Foster and G. Blenkinsop, "Surface Preparation of Aluminum and Composite Aircraft Materials", Lab Note 86-18, Defense Research Establishment Pacific, Dec 1986.

7. J. Gardner, "Precision Controlled Equipment Variables in Dry Stripping", Aerolyte Systems, 1985.

8. R. Roberts, "Interim Report on Stripping Paint from the First F-4E Prototype at Hill AFB, Utah on July 31, 1984", 21 Jan 1985.

9. S. Kelley, "Methods of Mechanically Removing Paint from Aircraft Surfaces", Robotics International/S.M.E., 3-5 Mar 1986.

10. S. Childers, et al.,"Evaluation of the Effects of a Plastic Bead Paint Removal Process on Properties of Aircraft Structural Materials",AFWAL-TR-85-4138, Dec 1985.

11. R. Pauli, "Use of Plastic Media Blast (PMB) on Composite Surfaces", United States Department of Defense Tri-Service Conference on Advanced Coatings Removal, 1-3 Mar 1988.

12. O. Deel, R. Galliher and G. Taylor, "Plastic Media Blast Materials Characterization Study", Battelle Columbus Division, July 1986.

13. R. Galliher, O. Deel and G. Taylor, "Plastic Bead Blast Materials Characterization Study--Follow-On Effort", Battelle Columbus Division, Nov 1986.

14. "Paint Removal and Surface Protection for Composites", A.D.Little, Inc., AF Contract No. F33615-87-C-5236, May 1988.

15. R. Bebak and J. Watson, "PMB Paint Stripping of Aircraft", Boeing Vertol Company Manufacturing Development Report No. 330036-1, May 1986.

16. J. Zimmerle, "Evaluating Plastic Media Blasting Operations at the Naval Air Rework Facilities (NARFS)", Technical Memorandum No. 71-87-09, Naval Civil Engineering Laboratory, Apr 1987.

17. "Graphite/Epoxy, Laminates, Fabrication and Acceptance of", McDonnell Douglas Process Specification 14240, Rev. B, 22 Dec 1982.

18. "Tape, Unidirectional, 350°F-Cure, Epoxy Resin-Impregnated Carbon Fiber (250°F Service Temperature)", Bell Helicopter Textron Specification No. 299-947-330, May 1985.

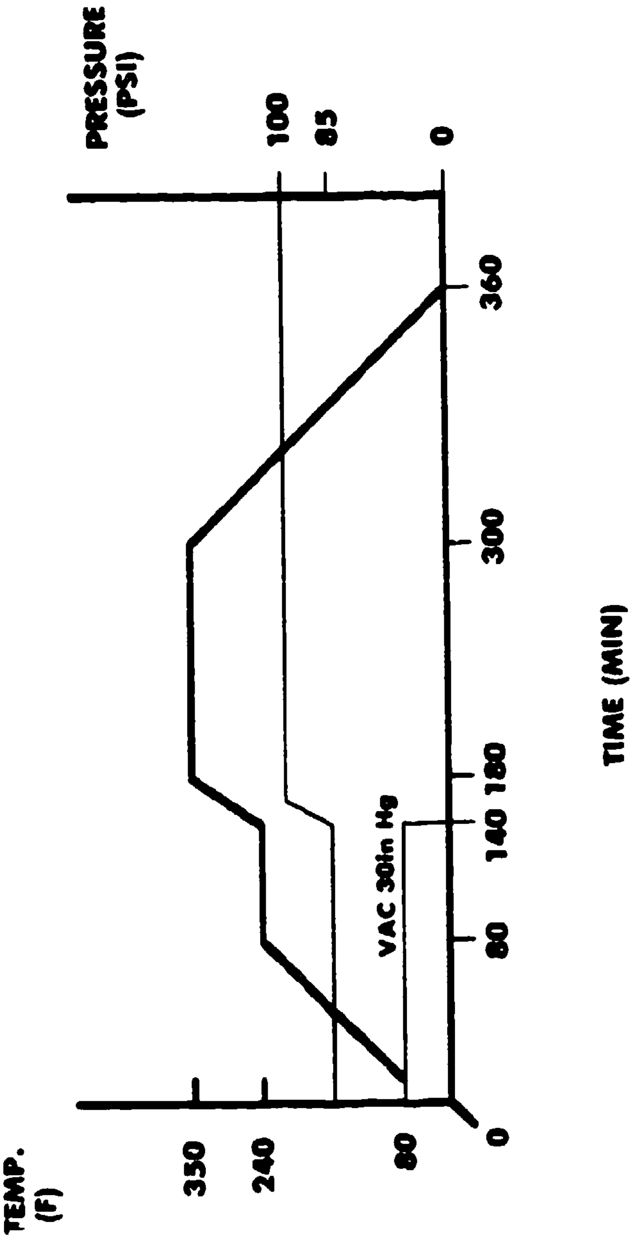


Figure 1. AS4/3501-6 Cure Cycle

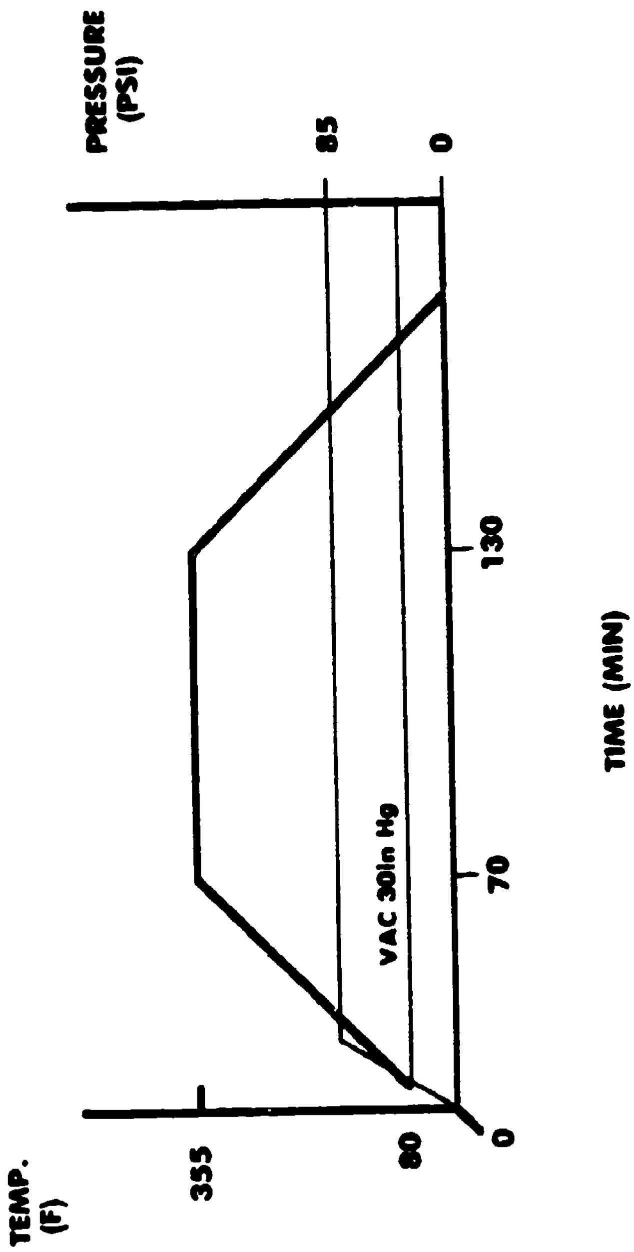


Figure 2. IM6/3501-6 Cure Cycle

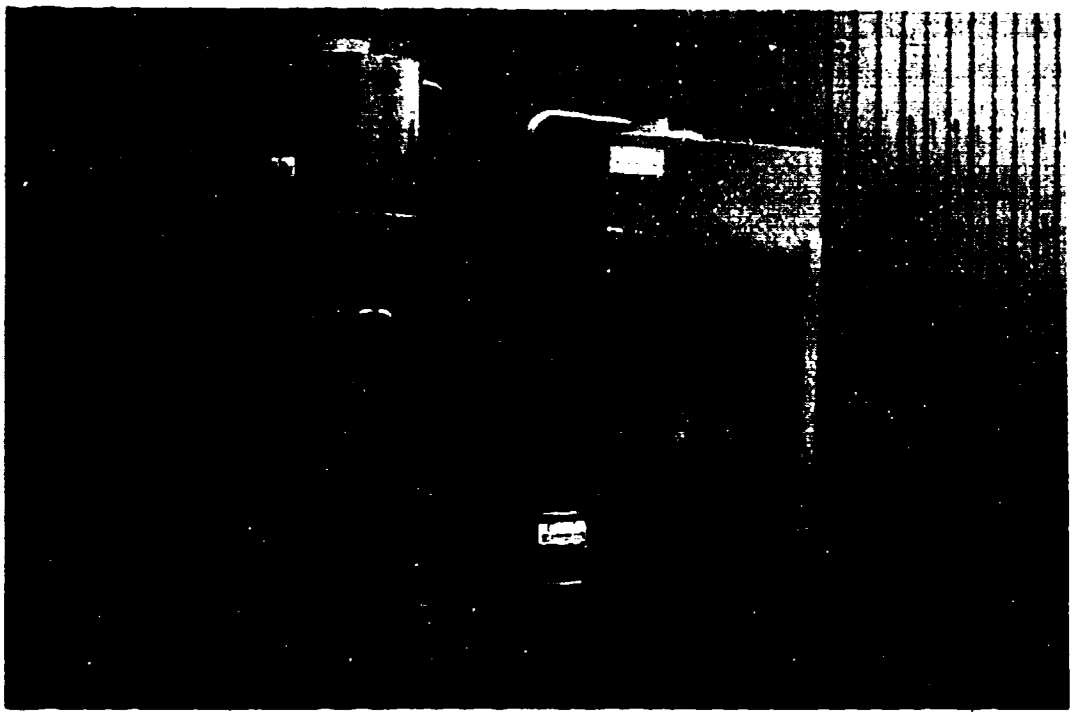
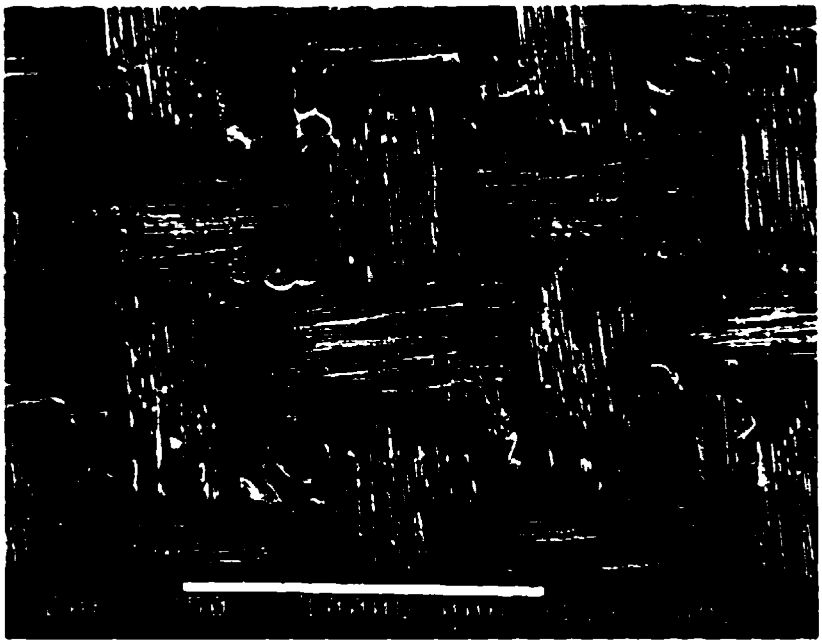
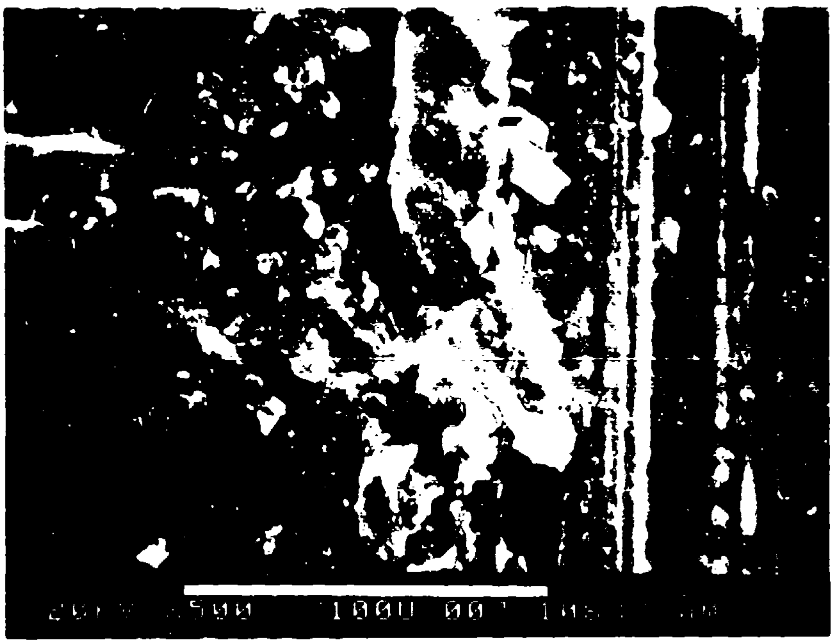


Figure 3. Plastic Media Blasting Equipment



(a)

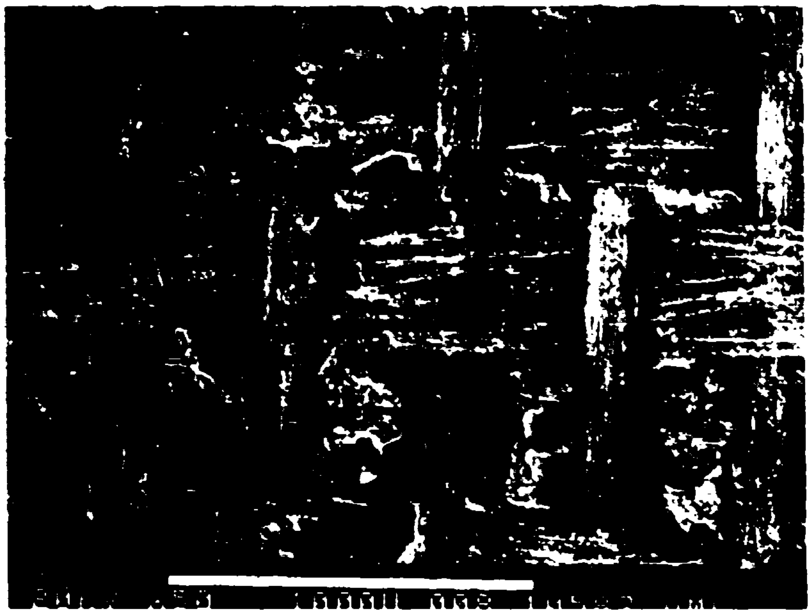
SEM PHOTOMICROGRAPH (50X)



(b)

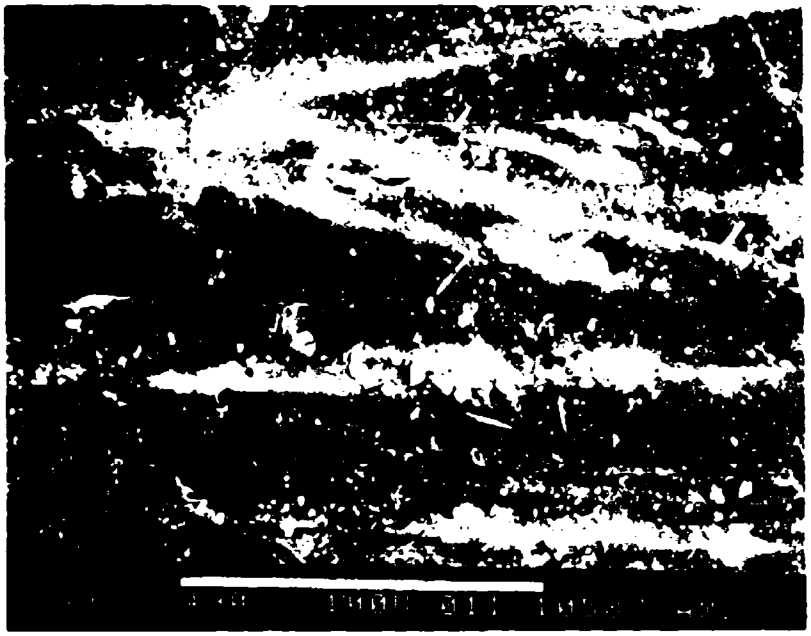
SEM PHOTOMICROGRAPH (500X)

Figure 4. Control Panel: No Damage (Unpainted, Unblasted Surface of AS4/3501-6 Graphite/Epoxy)



(a)

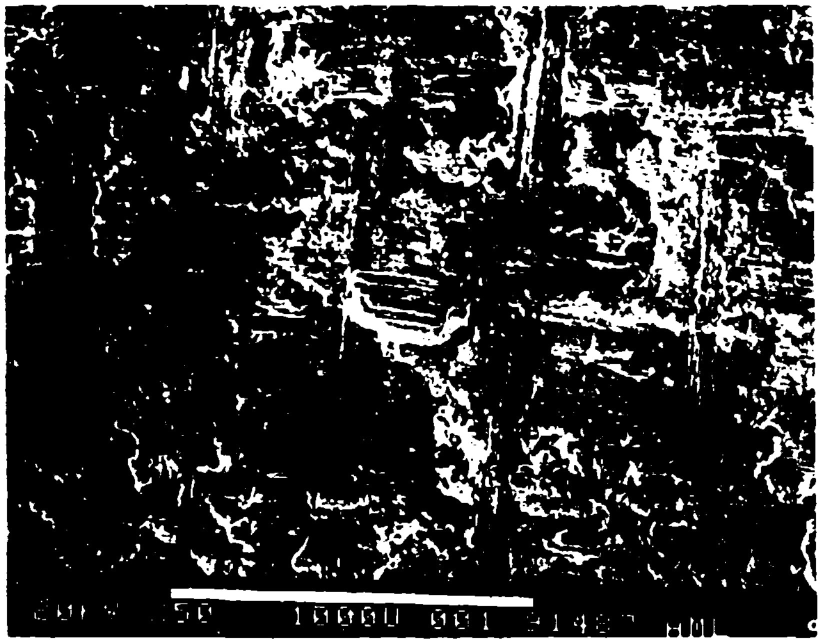
SEM PHOTOMICROGRAPH (50X)



(b)

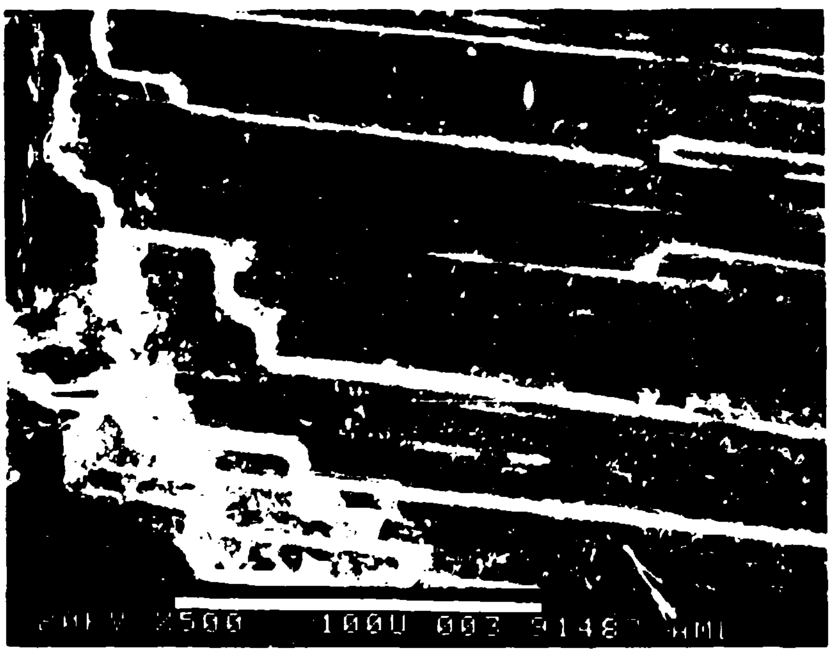
SEM PHOTOMICROGRAPH (500X)

Figure 5. Category 1: Minor Resin Abrasion (Type I Media, 90° Angle, 24" Distance, 35 psi, 20-30 Sieve Size)



(a)

SEM PHOTOMICROGRAPH (50X)



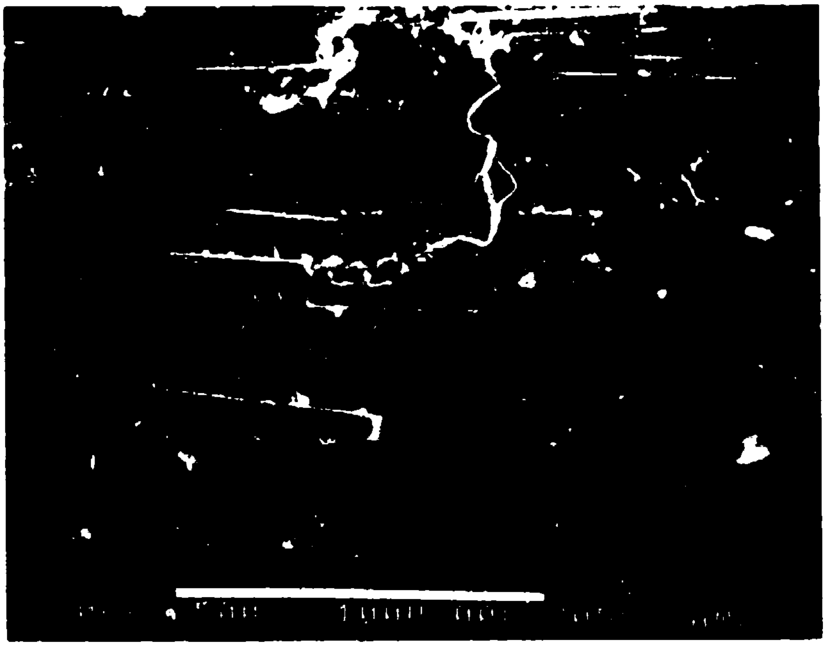
(b)

SEM PHOTOMICROGRAPH (500X)

Figure 6. Category 2: Minor Fiber Damage (Type II Media, 45° Angle, 12" Distance, 35 psi, 30-40 Sieve Size)

(a)

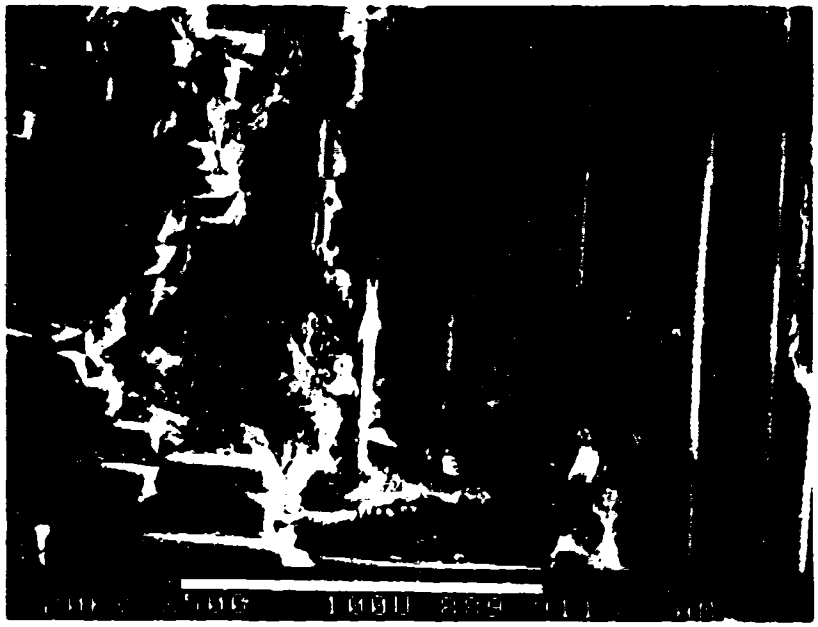
SEM PHOTOMICROGRAPH (50X)



(b)

SEM PHOTOMICROGRAPH (500X)

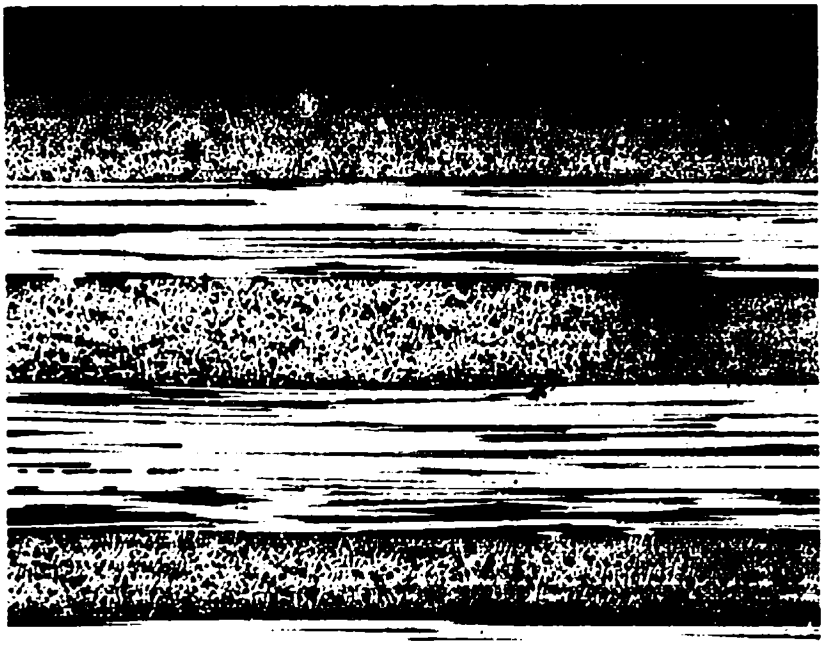
Figure 7. Category 3: Extensive Fiber Damage (Type II Media, 45° Angle, 24" Distance, 25 psi, 30-40 Sieve Size)



(a)

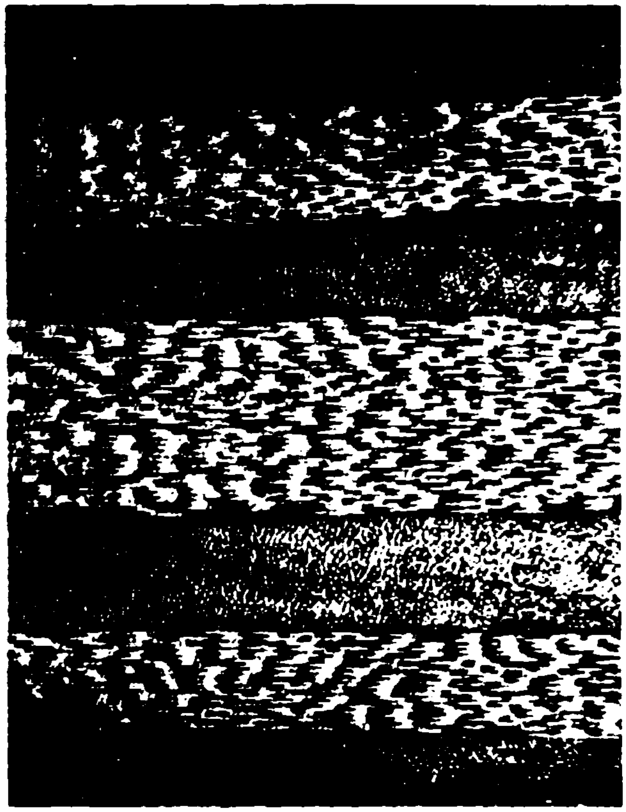
SEM PHOTOMICROGRAPH (500X)

Figure 8. Category 4: Damage Extends into the Second Ply (Type II Media, 90° Angle, 24" Distance, 35 psi, 30-40 Sieve Size, Extended Dwell Time of 30.5 Sec.)



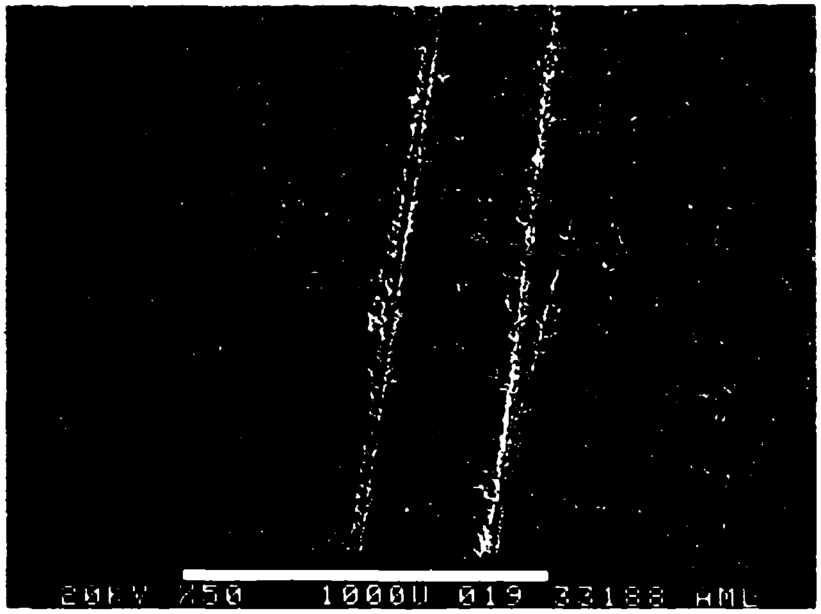
OPTICAL MICROSCOPY PHOTOMICROGRAPH (100X)

Figure 9. Control Laminate Cross-Section (Unpainted, Unblasted)



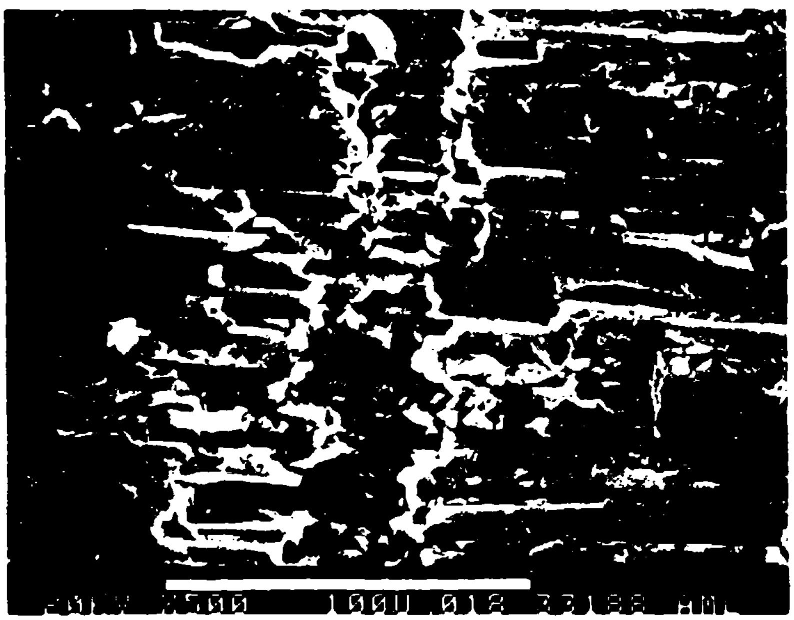
OPTICAL MICROSCOPY PHOTOMICROGRAPH (100X)

Figure 10. Sub-Surface Damage Investigation (Type II Media, 90° Angle, 24" Distance, 35 psi, 30-40 Sieve Size, Extended Dwell Time of 30.5 Sec.)



(a)

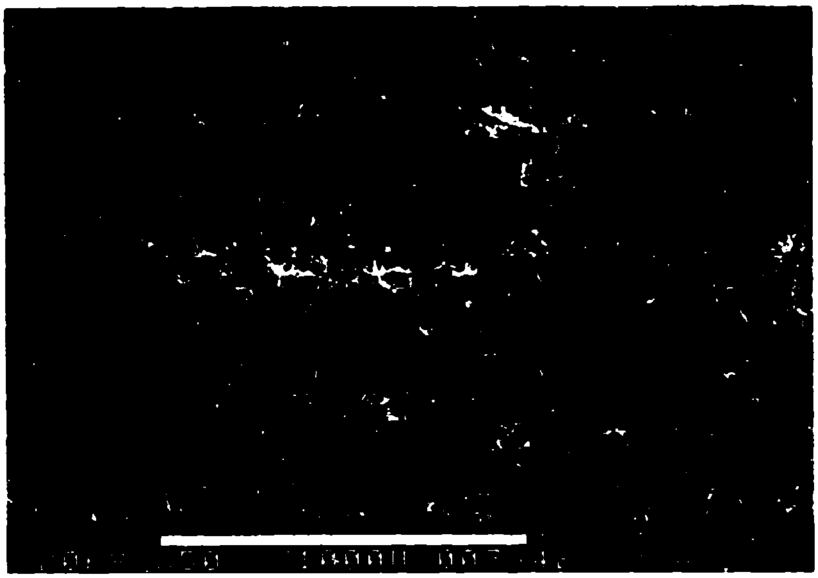
SEM PHOTOMICROGRAPH (50X)



(b)

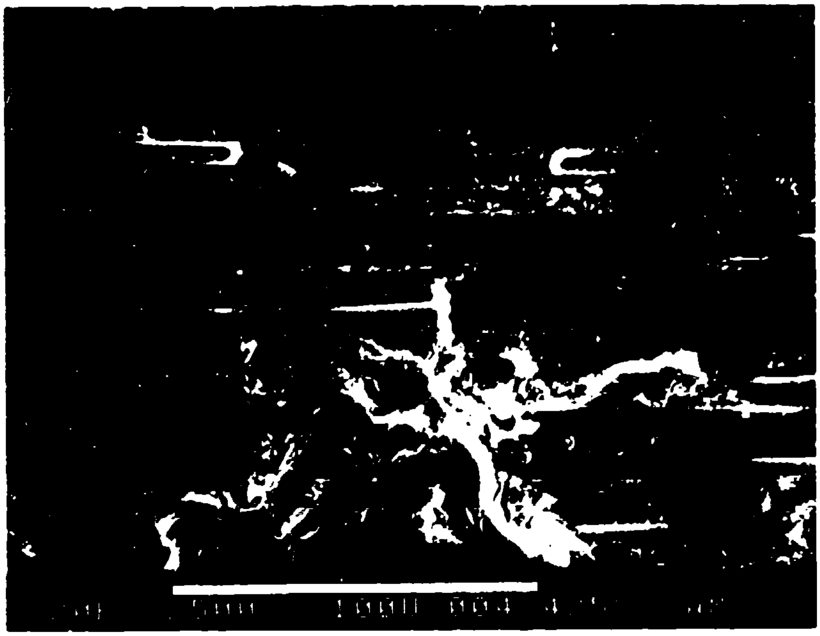
SEM PHOTOMICROGRAPH (500X)

Figure 11. Surface of GR/Ep After Coating Removal by Sanding (180 Grit)



(a)

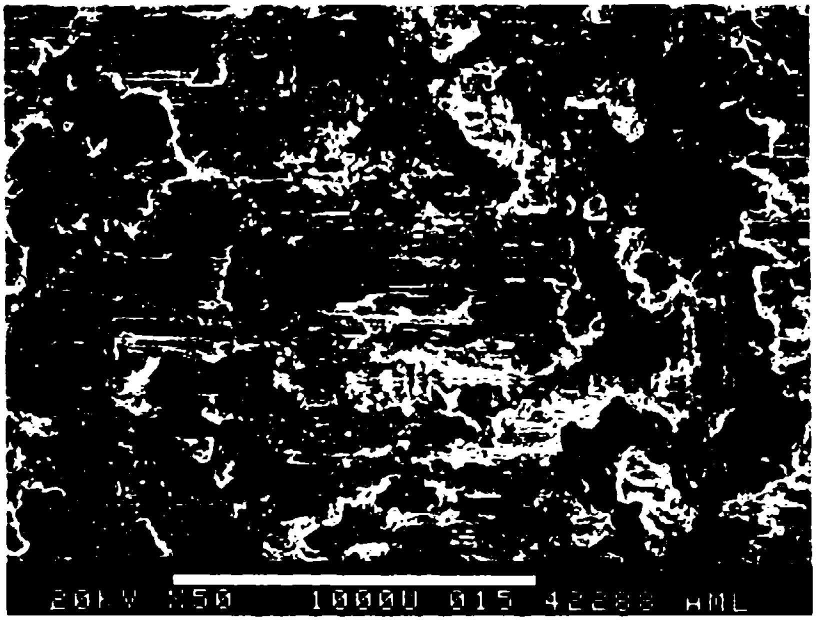
SEM PHOTOMICROGRAPH (50X)



(b)

SEM PHOTOMICROGRAPH (500X)

Figure 12. Surface of AS4/3501-6 after Four Paint/Blast Cycles (Type II Media, 90° Angle, 12" Distance, 25 psi, 20-30 Sieve Size)



(a)

SEM PHOTOMICROGRAPH (50X)

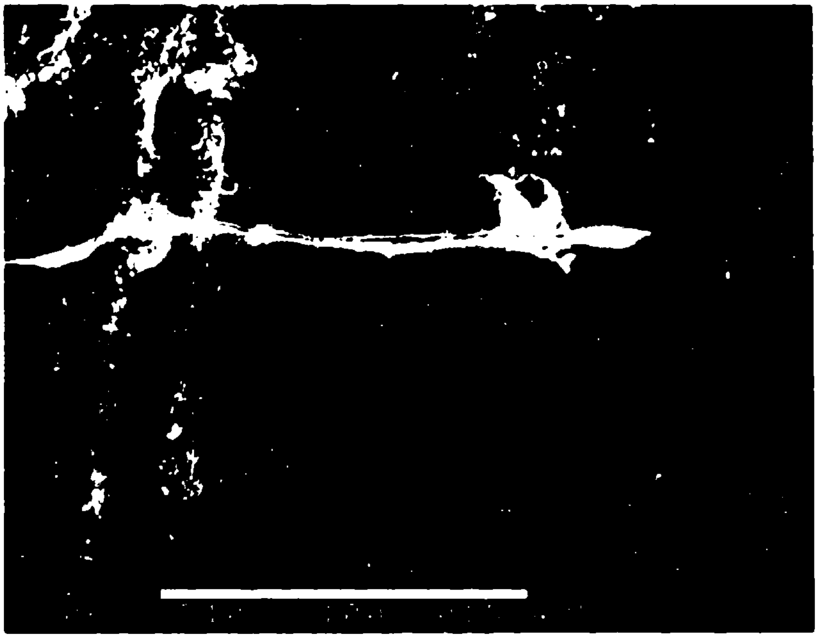
(b)

SEM PHOTOMICROGRAPH (500X)

Figure 13. Surface of IM6/3501-6 after Four Paint/Blast Cycles (Type II Media, 90° Angle, 24" Distance, 35 psi, 20-30 Sieve Size)

(a)

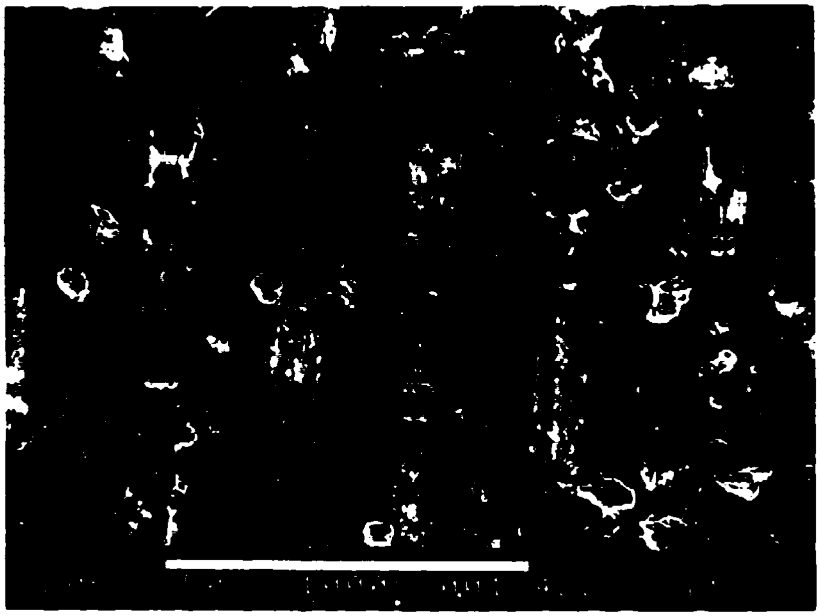
SEM PHOTOMICROGRAPH (50X)



(b)

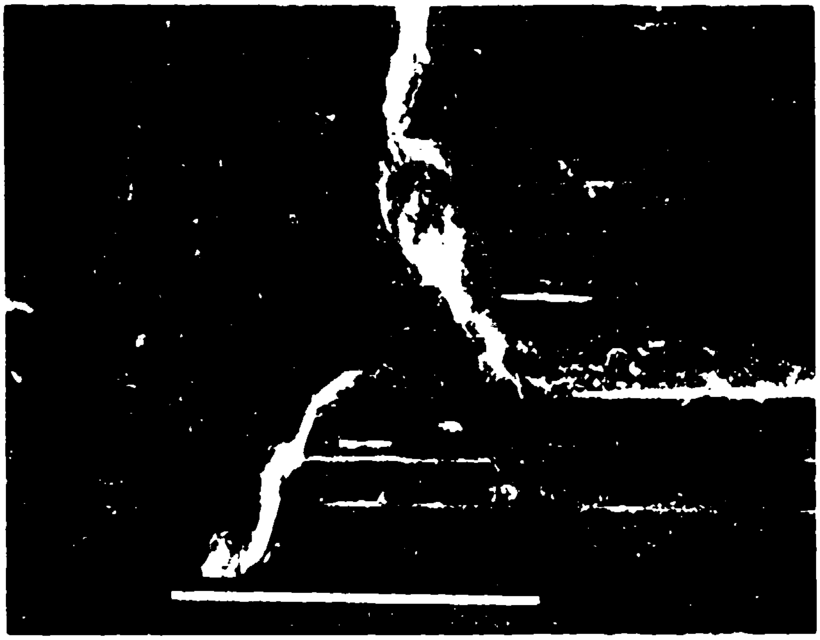
SEM PHOTOMICROGRAPH (510X)

Figure 14. Surface of AS4/3501-6 after Four Paint/Blast Cycles (Type I Media, 90° Angle, 12" Distance, 35 psi, 20-30 Sieve Size)



(a)

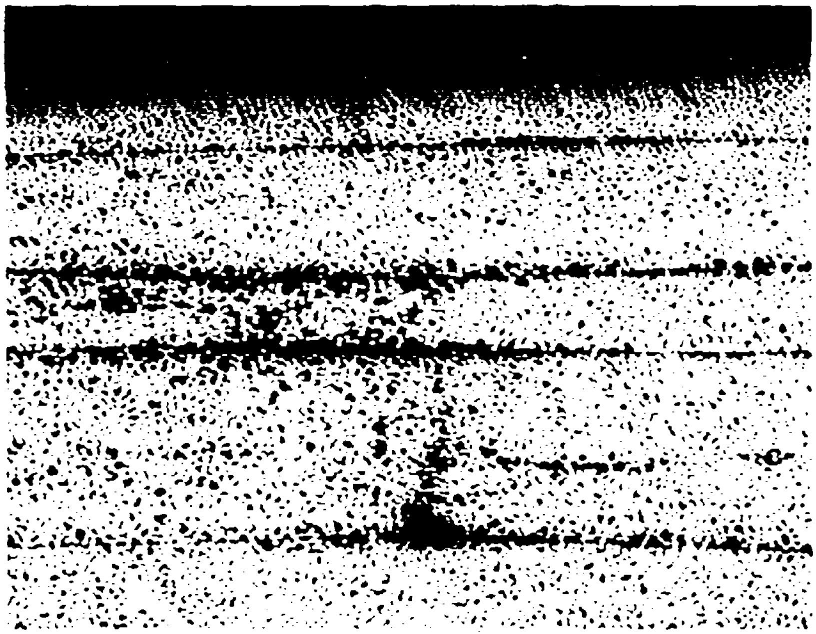
SEM PHOTOMICROGRAPH (50X)



(b)

SEM PHOTOMICROGRAPH (500X)

Figure 15. Surface of IM6/3501-6 after Four Paint/Blast Cycles (Type I Media, 90° Angle, 12" Distance, 35 psi, 20-30 Sieve Size)



OPTICAL MICROSCOPY PHOTOMICROGRAPH (100X)

Figure 16. Cross-Section of AS4/3501-6 after Four Paint/Blast Cycles (Type I Media, 90° Angle, 12" Distance, 35 psi, 20-30 Sieve Size)

TABLE 1 - Phase I Tests of 30-40 U.S. Sieve Size Media
(Two-level factorial design)

PMB PROCESS CONDITIONS				RESULTS	
MEDIA (Type)	NOZZLE PRESSURE (psi)	ANGLE (deg)	STAND OFF DISTANCE (inches)	COATING REMOVAL TIME (sec)	MICROSCOPY* RATING (0-4)
CONTROL	--	--	--	--	0
I	25	45	12	20.4	1
I	25	45	24	41.5	1
I	25	90	12	29.6	1
I	25	90	24	38.2	1
I	35	45	12	13.6	1
I	35	45	24	45.5	1
I	35	90	12	13.0	1
I	35	90	24	27.9	1
II	25	45	12	7.0	2
II	25	45	24	15.5	2-3
II	25	90	12	6.8	1
II	25	90	24	7.4	1
II	35	45	12	6.7	2
II	35	45	24	14.8	2-3
II	35	90	12	5.0	1-2
II	35	90	24	6.1	1

* Microscopy Rating Scale:

0 - no visible signs of damage.
1 - minor resin abrasion, release ply pattern clearly visible, no fiber damage.
2 - extensive resin abrasion, release ply pattern visible, local areas of fiber damage.
3 - release ply no longer visible, fiber damage over most of surface.
4 - damage extends into the second ply.

TABLE 2 - Phase I Tests of 20-30 U.S. Sieve Size Media

PMB PROCESS CONDITIONS				RESULTS	
MEDIA (Type)	NOZZLE PRESSURE (psi)	ANGLE (deg)	STAND OFF DISTANCE (inches)	COATING REMOVAL TIME (sec)	MICROSCOPY RATING (0-4)
CONTROL	--	--	--	--	0
I	25	90	12	15.1	1-2
I	35	45	12	9.0	1
I	35	90	12	7.3	1
I	35	90	24	11.9	1
II	25	90	12	5.3	1
II	25	90	24	6.7	1
II	35	45	12	3.4	1
II	35	90	12	2.0	1
II	35	90	24	2.7	1

* Microscopy Rating Scale:

0 - no visible signs of damage.
1 - minor resin abrasion, release ply pattern clearly visible, no fiber damage.
2 - extensive resin abrasion, release ply pattern visible, local areas of fiber damage.
3 - release ply no longer visible, fiber damage over most of surface.
4 - damage extends into the second ply.

TABLE 3 - Phase I Effects of Extended Dwell Time

PMB PROCESS CONDITIONS				RESULTS	
U.S. SIEVE SIZE	MEDIA (Type)	NOZZLE PRESSURE (psi)	ANGLE (deg)	STAND OFF DISTANCE (inches)	MICROSCOPY* RATING (0-4)
30-40	I	35	45	12	1
30-40	I	35	45	24	1
30-40	I	35	90	12	1
30-40	I	35	90	24	1
30-40	II	25	45	12	2
30-40	II	25	45	24	2-3
30-40	II	25	90	12	4
30-40	II	25	90	24	2-3
30-40	II	35	45	12	4
30-40	II	35	45	24	3
30-40	II	35	90	12	3
30-40	II	35	90	24	4

Extended dwell was five times the primer/topcoat removal time.

* Microscopy Rating Scale:

0 - no visible signs of damage.
1 - minor resin abrasion, release ply pattern clearly visible, no fiber damage.
2 - extensive resin abrasion, release ply pattern visible, local areas of fiber damage.
3 - release ply no longer visible, fiber damage over most of surface.
4 - damage extends into the second ply.

TABLE 4 - Effects of Repeat Blasting

PMB PROCESS CONDITIONS					RESULTS			
					AS4/3501-6		IM6/3501-6	
Media Size (US Sieve)	Media Type	Nozzle Pressure (psi)	Angle (deg)	Stand Off Distance (in.)	Mic. Rating	Avg. Paint Removal Rate(ft^2/min)	Mic. Rating	Avg. Paint Removal Rate(ft^2/min)
30-40	II	25	90	12	2-3	0.8	2-3	0.6
30-40	II	35	90	24	2-3	0.8	2-3	0.6
20-30	II	25	90	12	2	1.2	2	0.8
20-30	II	35	90	24	1-2	1.4	2	0.9
20-30	I	35	45	12	1-2	0.7	1-2	0.5
20-30	I	35	90	12	1	0.6	1-2	0.5

Distribution List Continued

	No. of Copies
Naval Air Development Center Warminster, PA 18974-5000 Attention:	
S. Thoman (Code 6064)	10
J. Kozol (Code 6063)	10
Code 8131	2
Center for Naval Analyses 4401 Font Ave. P.O. Box 16268 Alexandria, VA 22303-0268	1

Distribution List Continued

No. of Copies

Air Force Wright Aeronautical Laboratories
Wright-Patterson Air Force Base, OH 45433-6533
Attention:
Lt. L. Butkus (AFWAL/MLSE) 1
S. Childers (AFWAL/MLSA) 1

Office of Naval Technology
800 Quincy Street
Arlington, VA 22217
Attention:
J. Kelly (OCNR 225) 1

Aero-Tech
1256 Glenview Street
Reynoldsburg, OH 43068
Attention:
R. Galliher 1

Corpus Christi Army Depot
SDS CC-MPI-57
Corpus Christi, TX 78419-6010
Attention:
R. Williams 1

Robins Air Force Base
Georgia 31098
Attention:
R. B. Ivey (WR-ALC/MMEA) 1
Naval Civil Engineering Laboratory
Port Hueneme, CA 93043
Attention:
D. Conrad (Code 34040) 1
B. Winebarger (Code 620) 1

Hill Air Force Base, VT 84056
DO-ALC/MABEB
Attention:
T. Byers 1

Corpus Christi Army Depot
SDSCC-QLC-27
Corpus Christi, TX 78419-6010
Attention:
J. Burlington 1

Distribution List Continued

No. of Copies

Boeing Commercial Airplane Company
P.O. Box 3707
Seattle, WA 98124
Attention:
V. Gemmell (M.S. 73-43) 1

Federal Aviation Administration
New York Aircraft Certification Office
181 S. Franklin Avenue, Room 202
Valley Stream, NY 11581
Attention:
A. Maila 2

Naval Facilities Engineering Command
200 Stoval Street
Alexandria, VA 22332
Attention:
E. Ford 1

NADEP North Island
San Diego, CA 92135
Attention:
S. Montoya (Code 61222) Bldg. 3 1

Battelle Columbus Labs
505 King avenue
Columbus, OH 43201-2693
Attention:
O. Deel 1

U.S. Coast Guard
Aircraft Repair and Supply Center
Elizabeth City, NC 27909-5001
Attention:
O. Etheridge 1
E. White 1
J. Denscombe 1

Defense Technical Information Center
Bldg. 5, Cameron Station
Alexandria, VA 22314 1

DISTRIBUTION LIST

	No. of Copies
Naval Air System Command Jefferson Plaza One Washington, D.C. 20361-5300 Attention:	
B. Sturgis (AIR-53023)	5
Capt. C. Sapp (AIR-431)	3
J. Alker (AIR-431L)	1
D. Moore (AIR-5304C)	1
S. Bettadapur (AIR-5304D)	3
D. Carrillo (AIR-434F)	1
D. Jamieson (AIR-41121E)	5
M Dubberly (AIR-5302)	1
J Collins (AIR-5304)	1
Aerostructures, Inc. 1725 Jefferson Davis Highway Suite 704 Arlington, VA 22202 Attention:	
C. Troha	1
D. Ginsburg	1
NADEP Cherry Point Cherry Point, NC 28533-5030 Attention:	
D. Stewart (Code 35420)	1
B. Helms (Code 354)	1
G. Arthur (Code 35420)	1
NADEP Alameda Alameda, CA 94501 Attention:	
D. Klahn (Code 0541)	1
A. Viera (Code 0542) Bldg. 7	1
NADEP Pensacola, Pensacola, FL 32508-5300 Attention:	
O. Hayes (Code 340)	1
N. Reeves (Code 342)	1
Boeing Helicopter Company P.O. Box 16858 Philadelphia, PA 19142 Attention:	
B. Thompson (Mail Stop P38-50)	2